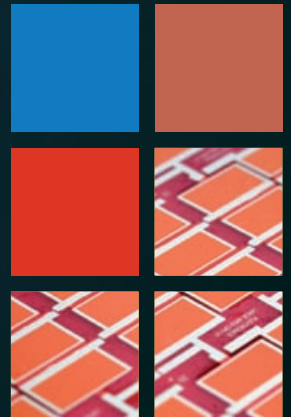




**NREL** National Renewable Energy Laboratory  
*Innovation for Our Energy Future*

# Energize Your



# Photovoltaics

NREL's Process Development & Integration Laboratory

The Process Development and Integration Laboratory (PDIL) at the National Renewable Energy Laboratory (NREL) is a unique collaborative facility where industry and universities can work closely with NREL scientists on integrated equipment to answer pressing questions related to photovoltaics (PV). The integrated equipment includes deposition, processing, and characterization tools. We work with a wide range of PV materials, from crystalline silicon to thin-films (amorphous, nano- and microcrystalline silicon, copper indium gallium diselenide, cadmium telluride) to organic PV.

**NREL uses the world's only integrated, high-vacuum tool set for 6-inch PV samples**

The PDIL integrates all the *data* to

- Automate control via recipes
- Share data easily and securely
- Facilitate analysis.

The PDIL integrates all the *tools* to

- Eliminate air exposure between steps
- Sequence steps in any order
- Incorporate combinatorial techniques.

The PDIL integrates all the *materials* to

- Provide greater device flexibility
- Allow diverse experts to work together
- Better support industry and universities.

## Maximize Infrastructure

In the PDIL, we integrate the tools and techniques used for deposition, processing, and characterization to

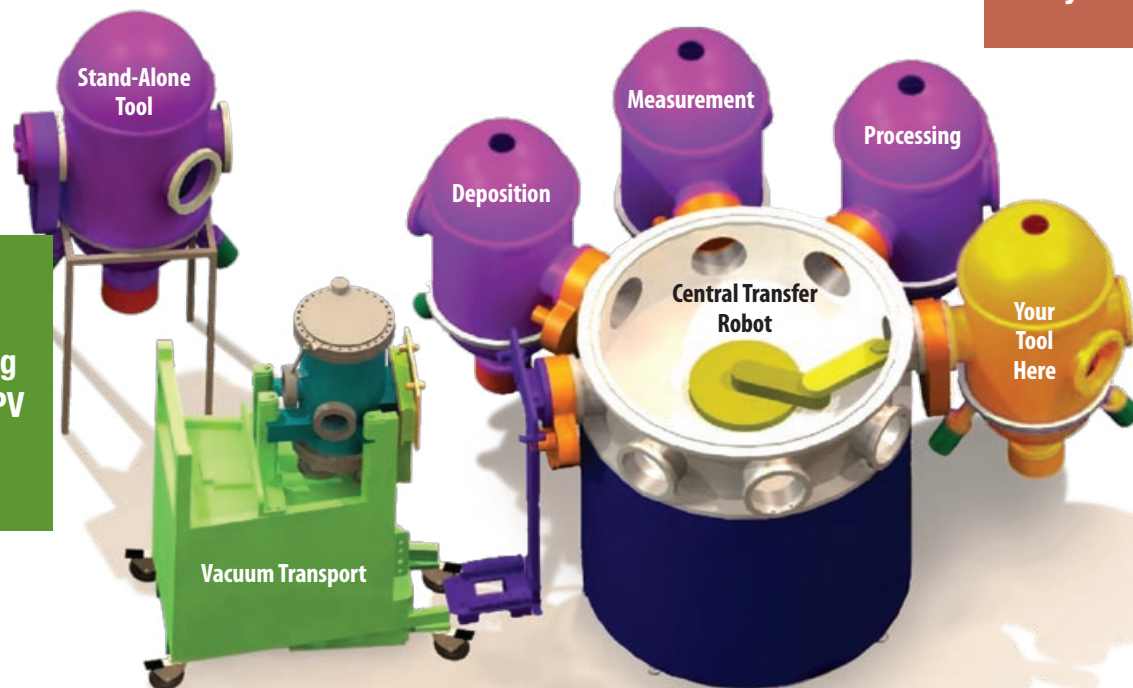
- Provide a baseline of world-class cells and materials
- Eliminate contaminants in the production process
- Control and characterize critical surfaces
- Create a flexible environment for material deposition
- Generate more useful data from well-designed experiments.

Our staff in the National Center for Photovoltaics has more than 2000 person-years experience in solar PV and semiconductor research and is uniquely qualified to

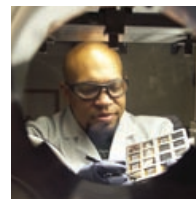
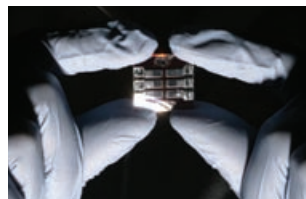
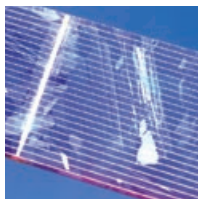
- Improve industrial processes
- Answer previously inaccessible research questions
- Develop new techniques, methods, and devices
- Offer the best expertise and data library in the industry
- Identify and solve solar cell efficiency problems.

**NREL is creating the world's largest modular system interface so you can add your own tools**

**NREL's PDIL is unique in serving a wide range of PV technologies**



Take a virtual tour of our system at [www.nrel.gov/pv/pdil](http://www.nrel.gov/pv/pdil)





## Accelerate Time to Market

In the PDIL, which is NREL's newest laboratory, you will

- Gain access to modular deposition, processing, and characterization capabilities
  - Common transfer interface
  - Standard sample size
  - Intra-tool transport supporting a given technology
  - Controlled ambient between tools at the molecular level
  - Inter-tool transport for samples up to 6 inches, which is unique in the world
- Access the latest information on worldwide trends and investments in solar PV R&D
- Work in facilities that bring people together
  - NREL subject-matter experts
  - Industry collaborators
  - University collaborators.

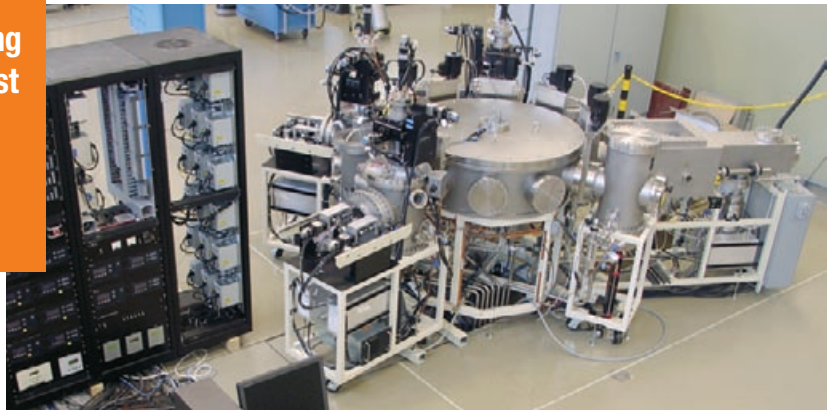
**NREL is integrating the world's largest collection of PV processes and diagnostics**

## Optimize Productivity

NREL is a global leader in identifying, mitigating, and troubleshooting solar energy production problems. In the PDIL, we have pioneered innovative technologies that integrate multiple disciplines to provide greater optimization.

The PDIL allows you to

- Use our combinatorial capabilities for screening studies
- Access integrated data systems for deposition and measurement
- Build materials systems that are unique to your device structure
- Access our complementary support system
- Access an extensive historical data collection.



## PDIL Tools

**NREL is working with industry to expand its tool set.**

### Silicon

- Plasma-enhanced chemical vapor deposition (PECVD) of amorphous Si and SiN:H
- Hot-wire chemical vapor deposition (HWCVD) of amorphous Si
- Very high frequency (VHF) CVD of amorphous Si
- Plasma etching
- Sputtering of TCOs
- High-resolution optical metrology (n & k)
- Photothermal deflection spectroscopy

### CIGS

- Co-evaporation of CIGS
- Chemical-bath deposition of CdS
- Sputtering of CdS, Mo, and transparent conducting oxides (TCOs)

### CdTe

- Close-spaced sublimation
- Chemical-bath deposition

- CdCl<sub>2</sub> treatment
- Physical vapor deposition (PVD) of TCOs
- Sputtering of metal contacts

### Silicon Wafer Replacement

- HWCVD of n-type and p-type Si
- Experimental CVD of Si
- Surface preparation (HF)

### Atmospheric Processing

- Ink-jet printing
- Ultrasonic spray deposition
- Sputtering deposition
- Evaporative deposition
- Rapid thermal annealing
- X-ray diffraction (XRD) / X-ray fluorescence (XRF)

### User Characterization

- Stylus profiling
- Ultraviolet-visible spectrometry
- Optical profiling

- Quantum efficiency (QE)
- Current-voltage (I-V)

### Measurements and Characterization

- Spectroscopic ellipsometry
- Resonance-coupled photoconductive decay (RC-PCD)
- Photoluminescence imaging
- Auger electron spectroscopy (AES)
- Sputtering / plasma etching
- PECVD studies
- X-ray photoelectron spectroscopy (XPS)
- Scanning electron microscopy (SEM)
- Atomic force microscopy (AFM)
- Wet chemistry
- Reflectance spectroscopy
- Optical processing furnace
- Semilab



## Partner with NREL

**We follow a three-step process for work within the Process Development & Integration Laboratory.**

**1**

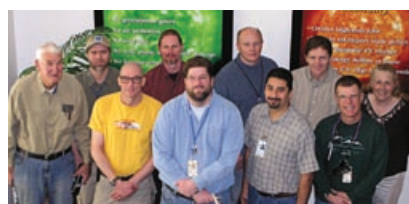
Submit your short project proposal, including goals, expected outcomes, scope, schedule, and required resources.

**2**

A panel quickly evaluates your proposal against established criteria to determine if your project is appropriate for the PDIL.

**3**

When your proposal is accepted, we finalize issues such as access to NREL facilities and protection of intellectual property.



## Contact

*For more information about working with NREL, please contact:*

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**For specific technical contacts  
visit [www.nrel.gov/pv/pdil](http://www.nrel.gov/pv/pdil)**



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